Spatially Generated Transportation Demands*

by

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Abstract

Transportation demanders are located at different points in geographical space and have differential access to modes. Central to the planning of transportation infrastructure is the aggregation of different shippers by mode over space. We estimate a modal choice model for rail and barge. However, shippers may not have direct access to one or both modes and incur access (truck) costs. The results indicate that access costs, barge and rail rates and shippers' attributes matter significantly in mode choice. The choice model is then augmented by rate functions defined over space and used to derive spatially generated modal demand functions.

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Spatially Generated Transportation Demands

1. INTRODUCTION

The demand for freight transportation is a derived demand. Shippers make shipment decisions that usually involve the choice of mode or modal combinations and size of the shipment. Shippers, however, are often located at different points in geographic space and have different costs to access modal options. These "access costs" are directly related to distance from rail/barge access points as well as shipper characteristics such as rail car loading capacity. For example, shippers located on a waterway with the ability to load barges are more likely to ship by barge than shippers located some distance away from the waterway that must truck or rail to the river access point. The latter shippers may have access to both rail or truck or just one of the other two surface modes and may have plant characteristics e.g., significant rail loading capacity which substantially reduces the cost of using rail. Finally, there are some shippers that have neither rail nor barge access. Their only option is to either truck to a rail or barge access point.

In this paper, we focus on the access that shippers have to transportation markets. To illustrate, we estimate a discrete choice model which is framed around the access shippers have to transport markets and then use the model to aggregate shipment decisions to provide "spatially generated transportation demands." That is, in analysis there are usually well-identified locations over which market clearing conditions are identified (e.g., ports). Typically, demands at these points are spatially generated transportation demands. These spatially generated demand functions then can be combined with supply conditions to establish equilibrium over a network (e.g, Anderson and Wilson (2004)).

The demand for freight transportation has historically taken two different approaches.[1] Early studies used aggregate data across locations, shipments and/or commodities and modeled aggregate demands. In locations, demand functions are aggregated across shippers in a region e.g., Wilson et al. (1988) or Yu and Fuller (2005). At the shipment level, there is a component of the literature in which individual shipment decisions are aggregated for each shipper. In such cases, demands are commonly modeled using a transportation cost function and associated factor demands by mode e.g., Oum (1979), Friedlender and Spady (1980), Westbrook and Buckley (1990). In the last 30 years, however, it has become more common to model transportation demands at a disaggregate level. In this framework, transportation demands are typically modeled at a shipment level using choice methods.[2] Generally, differences in options available to shippers are taken as differences in the choice set from which demand decisions are made. For example, in a model with three options that include truck, rail or barge, a shipper that is included on the waterway and has access to truck and rail would have a choice set with all three options. However, a shipper located off the waterway would have only truck and rail in the choice set. Estimation then proceeds with differential choice sets. Our paper differs from this approach by explicitly recognizing that shippers without access to rail, barge or both, have the option of shipping to an access point. We

[1] Oum (1989), Oum et al. (1992), Winston (1983; 1985), and Small and Winston (1999) each provide comprehensive surveys of the transportation demand literature. Boyer (1997) discusses the need to model spatial differences among firms. Apart from discrete choice models where econometricians may model differences in the choice set of different shippers, we are not aware of any models where access to modes is directly modeled.

[2] See, for example, Winston (1981), Inaba and Wallace (1989), and Train and Wilson (2004; 2005; and 2006). In the latter, Train and Wilson also combine revealed with stated preference data. Abdelwahab and Sargious (1992) also models shipment data using the Commodity Flow Survey. These data, as they recognize, do not have rate and shipment attributes available, but there is good information on shipments. They use supplemental data to provide the attribute data In recent work, Sitchinava et al. (2006) use a tobit model with stated preference data to estimate the level of production as a function of rates. In their model, mode choice is exogenous, and the level of production provides for individual demand functions for different shippers.

find that the costs of access have a very important effect on shipment decisions and form the basis for aggregation to points of interest. Specifically, the results are combined with models of access costs (truck rates) over distance, and aggregated to form demand functions which can be directly integrated with simulated equilibrium models which can be used to assess policy decisions related to infrastructure.

The advantage of our approach has become very important in the last 25 years. The railroad industry was deregulated by the Railroad Revitalization and Regulatory Reform Act (4-R Act) and the Staggers Rail Act of 1980 and subsequent legislation. Under regulation, the railroad network was substantial with over 180,000 miles of road. Under deregulation, the railroad network has decreased to less than 120,000 miles of road (Association of American Railroads). Further under deregulation, the number of Class I railroads has fallen to only seven.[3] Each of these changes implies fewer options available to shippers. As noted in Train and Wilson's (2004) survey of agricultural shippers in the Upper Midwest, about one-half of shippers have direct access to only the truck mode. That is, shipper cannot ship by rail or barge without first shipping by truck. Despite the fact that modal options are limited at the origin point, shippers do have a number of "routing" options. That is, to get the product to market, they are not limited to a single mode. Rather, they do have the option of shipping to a rail or barge access that are, in most cases, a lower cost mode, particularly for shipments of longer distances.

In addition to a reduction in the number of rail access points, there is also considerable interest in the spatial decisions of demanders in evaluating the costs and benefits of major infrastructure improvements. For example, the Army Corps of

[3] See Wilson (1997), Bitzan (1999; 2003), Bitzan and Keeler (2006) and Ivaldi and McCullough (2001) for more complete discussions.

Engineers (ACE) manage the nation's waterways. They routinely evaluate the costs and benefits of different investment decisions. Their models use aggregations of shipper decisions across both shipments and space to model the demands for waterway traffic. The demands are delineated by commodity and origin-destination "pools." A pool is a body of water between two different reference points. In most applications, a pool is commonly defined as the body of water between two locks on a river, and market demand functions are defined as a commodity, originating pool, and destination pool triple.

In the simulation models, ACE has used two different types of demand structures. In the Tow-Cost and Ohio River Investment Model (ORNIM) model, pool to pool demands are taken as exogenous up to a threshold rate typically taken as the least cost overland rail rate. At barge rates above this threshold level, pool to pool barge demands for the commodity are zero. A second demand structure is used in the ESSENCE planning model. In this model, the quantity varies continuously to this same threshold rate above which demands are zero. In both cases, the quantity shipped emanates from off-river shippers through a barge access point. Over the past five years, the National Research Council and others (NRC 2001; 2004a, and 2004b, and Berry et al. (2001)) have reviewed the models used by ACE. A primary criticism is the treatment of demands in the models. In particular, the various reviews point to the need to develop models that reflect the alternatives of spatially separated shippers. In the present paper, after demand function estimates are presented, we illustrate how the resulting estimates can be used to provide for aggregations across modes reflecting the spatial environment and locations of shippers.[4]

2. THE MODEL

The model is framed as a profit-maximizing choice between two alternatives. That is, shippers have a set of two alternatives. Each alternative *(c)* has a payoff (π^c) and the shipper chooses the alternative with the highest payoff. The payoff, however, consists of two components. These include a deterministic component ($\bar{\pi}^c$) which is commonly specified in terms of a function of unknown parameters and a random component (ε^c) which captures attributes that are not observed by the researcher.

To illustrate, we use the demand decisions of shippers in Eastern Washington who ship grain to Portland.[5] Jessup and Casavant (2004; 2005) provide comprehensive summaries of grain shipments and shippers in the region. A brief summary is provided here *en route* to modeling the decisions of shippers. Eastern Washington is one of the primary wheat producing regions in the United States. Almost all of the wheat travels to export terminals located in or near Portland, and almost all arrive by rail or barge. Eastern Washington and Portland are connected by an interconnected transportation system that consists of a series of rail lines and the Columbia-Snake Waterway. However, not all shippers have direct access to either rail or barge, and typically truck to points with direct access. Throughout access is defined as having the ability to load a particular mode. They may not be located on a river and must truck (or rail) to the river

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[4] Anderson and Wilson (2004; 2005a; and 2005b) develop theoretical models of spatial equilibrium and the locations of shippers under conditions of network congestion, pricing in spatial model, and the effects of space on the measurement of welfare vis a vis models used by ACE. The empirical research in this paper can be directly applied to their models.

[5] The same framework can be applied to multiple market outlets. In the case of Eastern Washington, the bulk of shipments are to Portland (Jessup and Casavant (2004; 2005)) and allows the illustration in this paper to be more concise.

to access the barge mode. Alternatively, they may not receive rail service. The premise of this research is that the access costs affect the mode (rail/barge) of shipper decisions that are central to defining spatially motivated demand models to examine equilibrium and the welfare effects of policy.

In the model, shippers have one of two options modeled: ship to Portland by a sequence of link movements involving barge i.e., barge alone or truck-barge; or to ship to Portland by a sequence of link movements involving rail i.e., rail alone or truck-rail. Shippers are distributed over space. Some have rail-loading facilities,[6] some have barge-loading facilities, some have both, and some have neither. Yet, they can still access both rail and barge facilities by using trucks.

In applying the model, two alternatives for each shipper are used (barge or rail). The connection to barge and/or rail facilities is treated as an access cost. As discussed above, a shipper is taken to choose barge if returns from barge exceed returns by rail. Returns for each alternative consist of a deterministic component $(\bar{\pi}_i^c)$ and a random component (ε_i^c). That is,

$$
\begin{aligned}
\pi_i^c &= \bar{\pi}_i^c + \varepsilon_i^c \\
&= f(rate_i^c, access_i^c, cars_i) + \varepsilon_i^c \qquad (1) \\
&= \beta^c + \beta_r * rate + \beta_a * access + \beta_{cars}^c * cars + \varepsilon_i^c
\end{aligned}
$$

In this model, the β's are unknown parameters to be estimated.[7] There is an alternative specific intercept β^c which captures mode specific differences i.e., unobserved

[6] In addition, the level of rail car loading capacity (the number of rail cars that can be placed on the shipper's siding) is an attribute in the model. Shippers with larger capacities are able to access lower rail rates and may find that loading costs are much lower for a given shipment size.

[7] In addition to rates and access costs, times in transit and reliability may also have an influence on demand decisions. These effects may fuel differences in modes which are captured in the alternative specific dummy variable. An alternative specific dummy variable is a standard term in choice modeling. There are

differences across barge and rail that are systematically different (e.g., speed, reliability, etc.) β^r is the coefficient on rate (technically, this captures the effects on profits from changes in rates). If zero, it means that rates do not affect the payoffs and does not affect decisions. This is a key coefficient in that if it is zero, demands are perfectly inelastic. However, in standard demand modeling, most researchers believe that rates are an important determinant of decision-making and should negatively influence the profits and choices of decision-makers. β^a is the coefficient on access costs to barge and rail terminals (access costs are measured by truck costs). In some cases, this is zero i.e., the shipper has direct access to barge and/or rail. In other cases, this is non-zero. That is, to access the option (barge and/or rail), the shipper must truck to the barge and/or rail terminal. β^c is the coefficient on rail car loading capacity. Rail car loading capacity (the number of rail cars that can be placed on the shipper's siding) is an important shipper attribute in that shippers with large capacity tend to obtain rate discounts (which is captured in the rate variable) and also incur lower loading costs which increases profits and, therefore, makes rail more favorable relative to barge.[8]

The empirical foundation for estimation is based on maximizing profit through a discrete choice (i.e., barge or rail). Let δ_i =1, if shipper *i* chooses to ship by barge; and zero if the shipper chooses to ship by rail. Since the choice involves both observed and unobserved determinates, the choice is the outcome of a random variable. Through the

two alternatives in this model. Barge is normalized to zero, and there is a rail dummy included in the specification. This captures unobserved differences in attributes across the alternatives.

[8] We note that there are two types of variables. The car loading capacity variable is a shipper attribute. It does not vary across the choices. Rates and access costs are alternative specific. That is, for any given shipper, these variables vary across the choice set. Both the alternative specific dummy and the car loading capacity variables require that they are normalized for identification (i.e., the ability to estimate the parameter). For both purposes, the coefficients on barge are normalized to zero, which means that the coefficients measure the effect on profit of rail relative to barge.

observation of the choice and an assumption of the distribution of the unobserved component, the econometrician can estimate the unknown parameters. More specifically, the empirical foundation is:

$$
\begin{aligned}
\Pr(\delta_i = 1) &= \Pr(\bar{\pi}_i^{Barge} + \varepsilon_i^{Barge} \geq \bar{\pi}_i^{Rail} + \varepsilon_i^{Rail}) \\
&= \Pr(\beta^{Barge} + \beta_r * rate^{Barge} + \beta_a * access^{Barge} + \beta_{cars}^{c} * cars + \varepsilon_i^{Barge} \geq \\
&\qquad \beta^{Rail} + \beta_r * rate^{Rail} + \beta_a * access^{Rail} + \beta_{cars}^{c} * cars + \varepsilon_i^{Rail})
\end{aligned} \tag{2}
$$

This type of model can be estimated with a wide variety of techniques and assumptions. The approach here is to estimate the model with a logit specification and the method of maximum likelihood. That is,

$$
\begin{aligned}
\Pr(\delta_i = 1) &= \Pr(\bar{\pi}_i^{Barge} + \varepsilon_i^{Barge} \geq \bar{\pi}_i^{Rail} + \varepsilon_i^{Rail}) \\
&= \frac{e^{\bar{\pi}_i^{Barge}}}{e^{\bar{\pi}_i^{Barge}} + e^{\bar{\pi}_i^{Rail}}} \\
&= \frac{1}{1 + e^{\bar{\pi}_i^{Rail} - \bar{\pi}_i^{Barge}}}
\end{aligned} \tag{3}
$$

Estimation proceeds after substitution of the definition of profits by logit. In the model, the intercept and the coefficient on car capacity are normalized to zero for barge, and the coefficients are interpreted relative to barge. The estimates are presented in section 4 after presentation of the data sources in section 3.

3. DATA

All data employed are the result of a survey conducted by the Social and Economic Sciences Research Center at Washington State University. Jessup and Casavant (2005) describe the data, survey techniques and provide a copy of the survey instrument. The survey was pre-tested and reviewed both by academics and target survey recipients. It was conducted in the fall of 2004. There were 167 firms contacted, representing 414 warehouses. Of these, 80 firms completed the questionnaire, and provided information for 181 warehouses.[9]

In these data, there are a number of descriptive statistics of immediate relevance. First, the choice data collected consisted of six alternatives. Three of these involve barge as an option, while two involved rail as an option.[10] The other alternative was "other". In about 25 percent of the cases (51 cases), shippers reported that they only had one alternative (the one used) and as such were omitted from the estimation. Another 25 percent (49 cases) involved other locations/modes.[11] After removal of observations with missing values and a small number of responses that substituted within the same mode, there were 55 observations which comprise the data used.

Table 1 provides descriptive statistics. There are 35 shippers that chose rail, and 20 shippers that chose barge. Overall, shippers have an average of about 11 cars rail loading capacity. Those that ship by rail (the column with Rail=1) tend to have more car capacity than barge shippers (about 16 versus 2 cars). The rates per ton are lower (as

[9] After adjusting for ineligible, return to sender, etc., the response rate was 70 percent for grain businesses and 35 percent for non-grain business.
[10] In the survey instrument (see Jessup and Casavant (2005)), the six alternatives are: 1. Truck to Pasco, WA and then barge to Portland; 2. Truck to a different river terminal then barge to Portland; 3. Rail to Portland; 4. Truck to rail, and rail to Portland; 5. Barge to Portland; and 6. Other.
[11] Only two of these trucked to Portland, six were of non-grain products, and 21 reported destinations other than Portland. It is not known whether the destinations "other than Portland" were stops along the way to Portland or not. The other 20 did not provide any information.

expected) for barge. For all shippers, the rate per ton by rail is about $11.66, while by barge the rate per ton is about $8.28. These averages are about the same for shippers that choose barge and for those that choose rail. The access cost (truck cost per ton) is larger for barge than for rail, but again there is little difference across rail and barge shippers. One reason for the difference in rail and barge access costs is that the mean distance to barge access points is about 98 miles (for all shippers), while for rail access points the distance is only about eight miles. Of course, the distance to barge access points tends to be smaller for barge shippers than for rail shippers (about 84 miles versus 106 miles). This reflects the basic point that shippers that use barge tend to be "closer" to the waterway than shippers that use rail. Finally, the barge and rail distances reflect the distance of the barge and rail legs of shipments. Rail distances tend to be longer than for barge, but it is noted that the distance to barge access points is also larger for barge movements.

Table 1.—Descriptive Statistics.

	Overall		Rail=1		Barge=1	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Barge=1/Rail=0	0.36	0.49	0.00	0.00	1.00	0.00
Rail Car Capacity	10.78	22.76	15.74	27.09	2.10	5.88
Rate/ton-barge	8.28	1.35	8.21	1.33	8.41	1.42
Rate/ton-rail	11.66	2.82	11.51	2.31	11.91	3.61
Access cost/ton-barge	7.32	3.49	7.92	2.91	6.26	4.19
Access cost/ton-rail	2.66	3.69	2.75	4.29	2.51	2.41
Barge Distance	252.67	53.75	248.23	37.07	260.45	75.18
Rail Distance	345.44	93.11	364.63	60.19	311.85	127.64
Distance to Barge	97.67	66.14	105.66	50.43	83.70	86.95
Distance to Rail	7.84	8.81	5.94	7.92	11.15	9.48
	N=55		N=35		N=20	

Note: The categories labeled Rail=1 indicates that the chosen alternative involved rail; while the category labeled Barge=1 indicates that the chosen alternative involved barge.

4. EMPIRICAL APPLICATION AND RESULTS

The logit model of section 2 was estimated with estimates reported in Table 2.[12]

Table 2.—Coefficient Estimates

Variable	Coefficient	Standard Error	t-value
Rail Dummy	0.10	0.51	0.2
Rate per ton	-0.64**	0.33	-1.91
Access cost per ton	-0.46**	0.25	-1.82
Car Loading Capacity	0.09**	0.05	1.93

Note: A ** indicates statistical significance at the 90 percent level.

Despite the fact that there are only 55 observations, the model appears to fit the model reasonably well with a chi-square statistic of 20.26 with four degrees of freedom, and the log-likelihood at convergence suggests a likelihood ratio index of .2658. Further, the coefficients are of the *a priori* expected sign and, and with the exception of the rail dummy, are statistically significant at the 90 percent level.

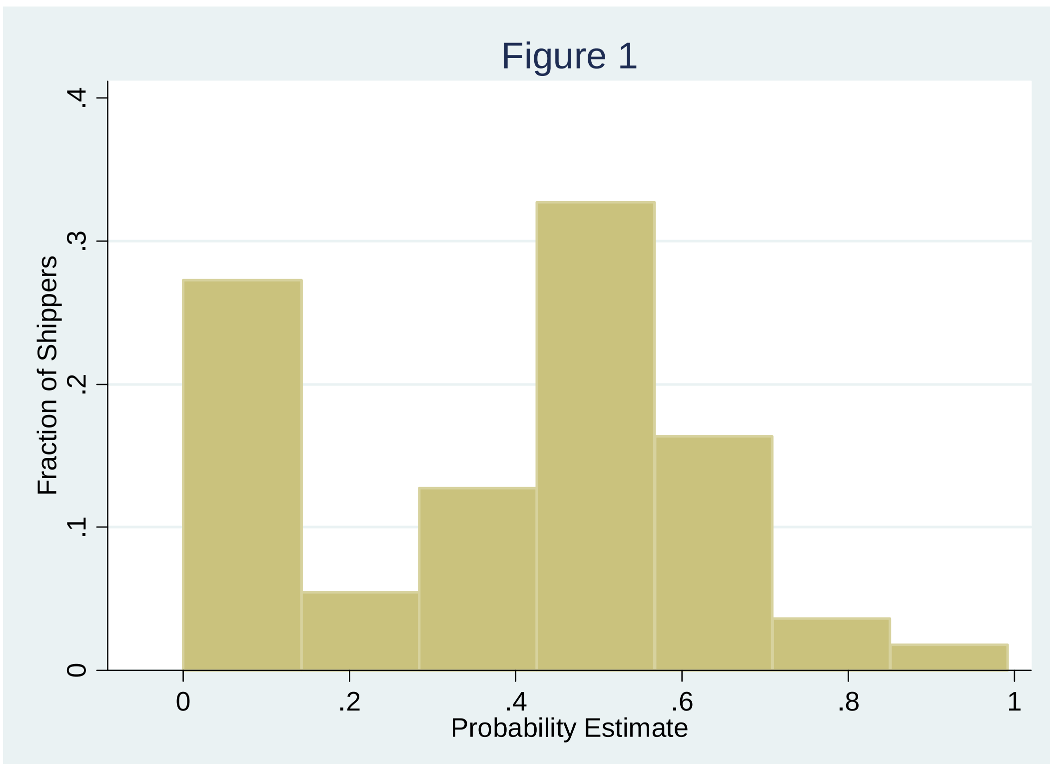
In this model, the alternative specific dummy is positive, but not statistically significant. A positive value means that relative to barge, profits are higher for rail.[13] The coefficient on rate is negative and statistically significant at the ninety percent level. This suggests that profits decrease as the rate increases. The coefficient on access is also

[12] A variety of other models were also examined. Specifically, we imposed a constraint that the coefficients on rate and access were identical. A likelihood ratio test yielded a chi-square statistic of 6.88 with one degree of freedom which suggests that the restriction cannot be imposed at the 5 percent level. In addition, if only total rates matter, then the rail dummy and car loading capacity coefficients are both zero, and the rate and access coefficients equivalent. A likelihood ratio test with these three constraints yielded a chi-square statistic of 8.9 which suggests that the three restrictions cannot be imposed at the 5 percent level. Finally, a referee suggested that the choices may be jointly determined with capacity. To evaluate, we regressed capacity on distance from river, but did not find any statistically meaningful results. We also removed capacity from the model estimated and obtained estimates on the rate and access coefficients that were nearly identical to those reported.

[13] This coefficient reflects systematic differences across attributes of the mode that are not included in the model (speed, reliability, etc.).

negative and statistically significant at the 90 percent level. This suggests that as the costs of trucking to a barge or rail terminal increases, payoffs decrease, and the likelihood of using barge or rail decreased. That is, as access costs increase for a particular alternative relative to the other, the likelihood of that alternative decreases. Finally, the coefficient on rail car loading capacity is positive and statistically significant at the 90 percent level. This means that profits for shippers that have greater car loading capacities have higher profits from rail relative to barge.

A histogram of the probability estimates (the probability of using barge) is given in Figure 1 (below).



The histogram is quite interesting. There is a cluster of probabilities close to zero, indicating that there are a number of shippers are essentially “rail-captive”. Inspection of the probability estimates suggests that these tend to be shippers with a lot of rail car capacity. There are also a number of estimates that lie close to .5 (over 30 percent of the shippers). Thus, the predominant number of shippers are “on the margin” i.e., probabilities of shipments involving barge is at or near .5. Such shippers are likely “reactive” in their mode choice to changes in barge, rail or truck rates, and point to shippers that form the source of downward sloping demand functions derived below.

5. ILLUSTRATIONS

There are numerous illustrations and uses of the model. These include the use of the probability function to consider adjustments of shippers to changes in barge and rail rates, the costs of access (i.e., truck costs), distance from the waterway, car loading capacity. The results can also be used to define market areas of rail and barge and, perhaps, most importantly, pool level demands. Each is considered in turn. We note that in all illustrations, we assume that shippers have rail and barge options. However, the survey data collected here and in other surveys, suggest that some shippers do not view themselves as having more than one option in the choice set. Such cases can be easily incorporated in the calculations that follow simply be specifying the mode choice as a zero or a one.

The basis for the choice models is that profits depend on multiple attributes, not just rates. For the illustrations, reference points for the attributes other than barge rate are necessary. For this purpose, the attributes used are based on consideration of sample means and medians. The specific values used are:

Cost of access for rail and barge (truck costs $5 per ton)
Rail rates ($11.6 per ton)
Barge rates ($8.3 per ton)
Car loading capacity (consideration of 0 cars and 25 cars)

5.1 Probabilistic Responses of Shippers to Changes in Barge Rates

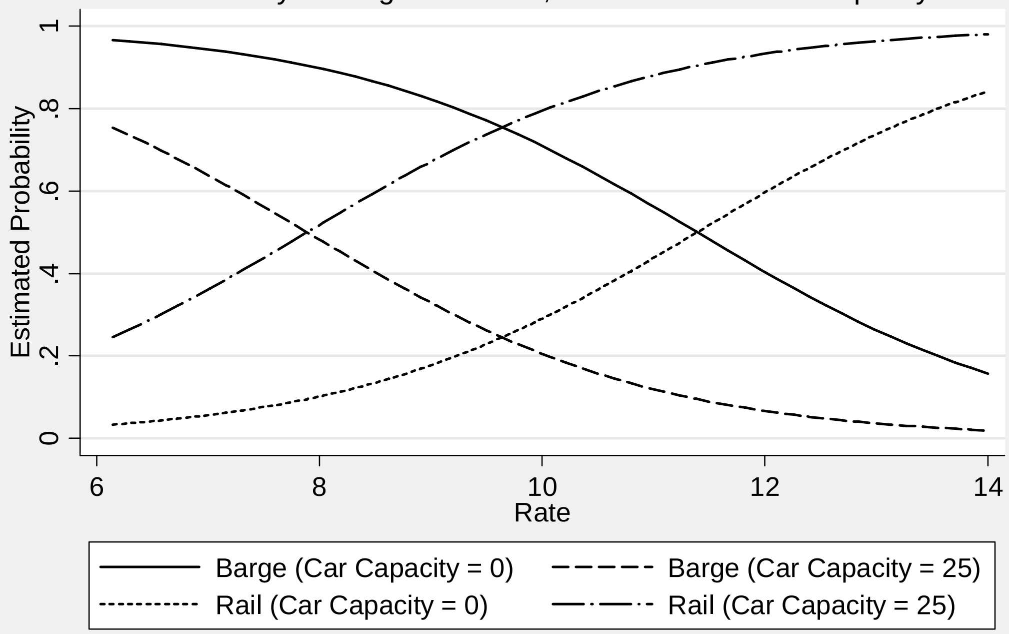
Given the reference points above, the probability of using barge and the probability of using rail are calculated using a range of barge rates and presented in Figure 2. Note these two probabilities must sum to one. Further, since rail shippers with lots of car loading capacity likely have a very different probability schedule than shippers without any car capacity, two sets of schedules are presented – one set for shippers with 25 car capacities and one for shippers with no rail car capacity.

As can be seen in the schedules, the probability of using barge at low barge rates is quite high as expected, and the probability of using rail is quite low. As rates rise, however, the probability of using barges falls and rail rises. These results are the foundation for the statement that demand functions slope downward in the context of a choice model. That is, controlling for all else, the likelihood of using barge falls as rates increase. Of course, similar figures can be presented for rail shippers.

There are large differences between shippers with 25 car loading capacities and shippers with no rail capacity. At the mean barge rate of $8.3 per ton, the difference is about 45 percentage points. That is, at mean values, the probability of using barge is about 90 percent for shippers without rail car capacity, and only about 45 percent for shippers with 25 car capacity. Indeed, equating the probability of using barge and rail for each shipper type identifies the "transition" point wherein the discrete predicted outcome changes. For the 25 car capacity shipper, the barge rate necessary for a switch to barge is less than $8.3 per ton. For shippers without rail, it is about $11 – a $3 difference.

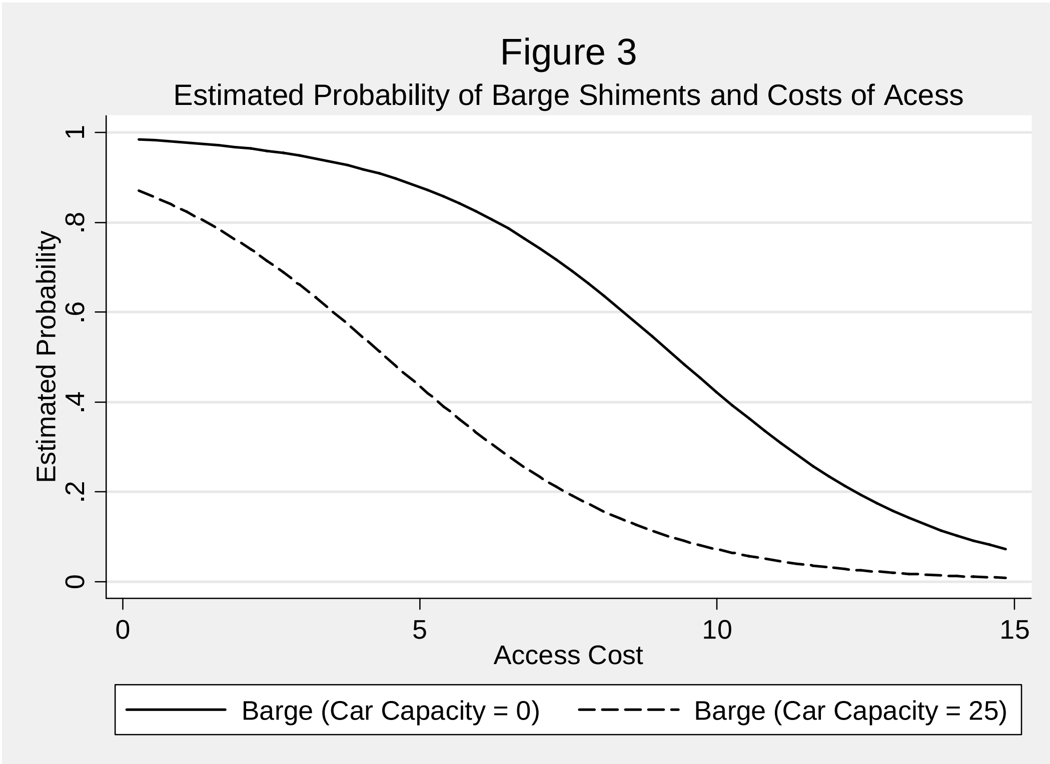
Figure 2

Probability of Barge Shiments, Rates and Rail Car Capacity



5.2 Probabilistic Responses to the Costs of Access

Shippers without access to barge must truck to barge terminals if they choose barge. An important attribute is, of course, the cost of access. Indeed, as might be expected as the cost of accessing barge increases, the likelihood of using barge falls (and rail increases). This is illustrated with Figure 3. The probability of using barge is extremely high for shippers with low costs of accessing the river, particularly if they do not have rail access. As the costs increase, the likelihood of using barge falls. This means that shippers with a high cost per ton of shipping to the waterway (e.g. $10 per ton) have a small likelihood of using the waterway, especially for shippers with rail access and significant loading capacity.



5.3 Probabilistic Responses to Access Distance and Costs

As stated above, access costs are measured as truck cost per ton. Of course, truck costs per ton are a function of distance. This allows *spatial considerations* to be directly integrated into the choice function. In illustrating, truck rates are fit to distance and the result is used in a constructed transportation network. There are two possibilities in construction of the latter. First, we can vary the distance to the waterway, inferring the truck rate *given a constant cost of accessing rail.* Such a procedure means that the distance to the rail access point is fixed as distance to the waterway changes. Second, we can fix the locations of the rail and barge access points and then vary the distance across different shippers. Both procedures were followed and yield similar qualitative results. In the following, we focus on the second approach.

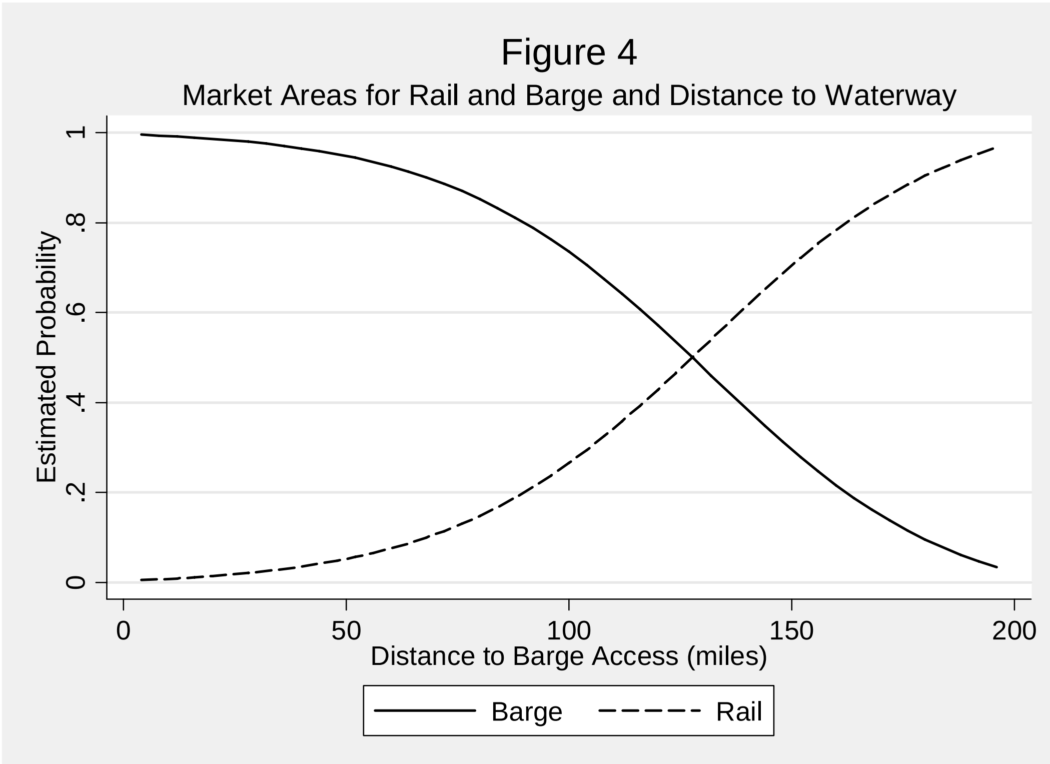
To develop the effects of space on choices, the relationship between truck rates and distance must be determined. This relationship is well known to be a positive relationship (rate per ton as a function of distance), but increasing at a decreasing rate due to the tapering principle. To estimate the relationship, truck rates observed in the sample were regressed on associated distances with a double-log specification.[14] The results are:

$$\log(\text{truck rate}) = -0.366 + 0.526 * \log(\text{distance to access point}) \quad (4)$$
$$(-2.25) \quad (14.29)$$

Where t-values are in parentheses indicate a strong relationship which is also reflected with an R-square of about 80 percent.

Given the relationship between access costs (truck rates) and distance, we now fix the distance between rail and barge access points at 200 miles. We then consider the probability of using barge as distance to water increases (and rail falls). This changes the relative access costs of using barge and rail, and sketches out the market area for each. To calculate the probabilities, reference points for barge and rail rates are needed. We fit double log specifications to each and used predicted values for barge and rail of $9.3 and $11.1 per ton, respectively. These correspond to barge and rail legs of 350 miles in the shipment. The result is provided in Figure 4.

[14] We also estimated the model with a linear specification. The results were very similar in terms of predicted values and, when the log predictions were converted to levels, the correlation between the two was in excess of .95. Because of the tapering principle, the rest of this paper is based on predictions from equation 4.



The figure indicates that the probability of using barge is quite high close to the river and falls for shippers located "closer" to rail. The two are equivalent for a distance of about 125 miles.

6. DEMAND SCHEDULES

A primary feature of this research is to estimate demand schedules for shippers that can be aggregated to the pool level. As discussed earlier, this is a central definition of markets in ACE planning models. In this section, we illustrate choice models such as that presented earlier can be used to define pool level aggregate demands. In this particular case, we assume that there are two terminals, a river terminal and a rail terminal, located 100 miles apart on a line. There are 50 shippers and each ships 100 tons for a total quantity of 5000 tons.[15]

Each of the shippers faces a different set of access costs and, therefore, has different probabilities of using barge (and rail). Therefore, the demand for each mode (not the function but the expected quantity shipped by each shipper)[16] differs by location. In presenting the demand schedules, there are two levels—the individual level and the pool level. Each is presented in turn.

6.1 Individual Demand Schedules of Spatially Separated Shippers

First, at the shipper level, there are three schedules presented below. Each shipper ships a total of 100 tons, shipper one is 10 miles from the river, shipper two is 50 miles from the river, and shipper three is 10 miles from the rail terminal. In Figure 5, the expected barge quantity for each shipper is plotted against rate – these form the demand equation for spatially differentiated demands.

This figure gives expected shipper level demand functions for barge for shippers located 10, 50 and 90 miles away from the waterway. As expected, at very low barge rates, all quantities go by barge, given the rail rate. As the barge rate increases, shippers located "near" the river continue to select the river, while shippers located further away from the river begin to substitute to rail. At the predicted barge (and rail) rates for a 350 mile movement ($9.1 and $11.3 per ton), shippers located near the river continue to select

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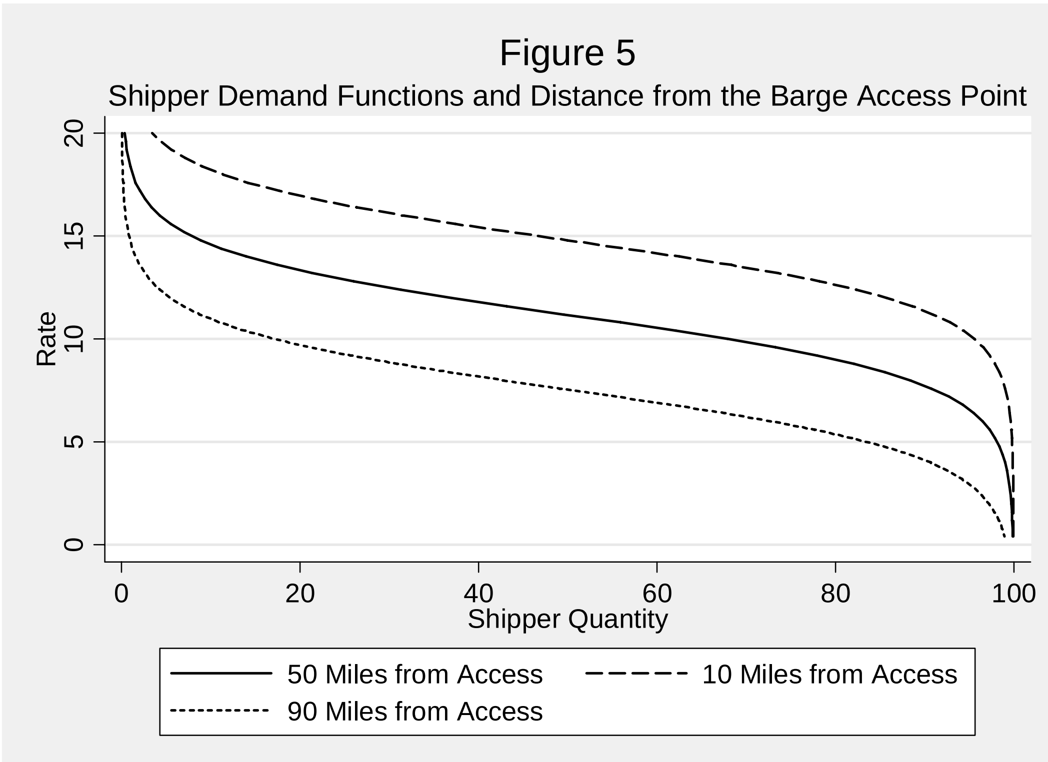
[15] In related research, Train and Wilson (2004) provide evidence that the 100 tons shipped by each shipper is also a function of the rates confronted by shippers, and this relationship can also be integrated. For this illustration, quantities are taken as exogenous, but note that they can be integrated into the analysis.

[16] This is in a statistical sense. For a shipper that has 100 tons, and a 60 percent chance of using barge, we use 60. An alternative would be to predict that they would use barge and allocate 100 tons to barge.

truck-barge with a high probability, while shippers close to rail are more likely to use truck-rail. According, quantities by barge are lower for such shippers.

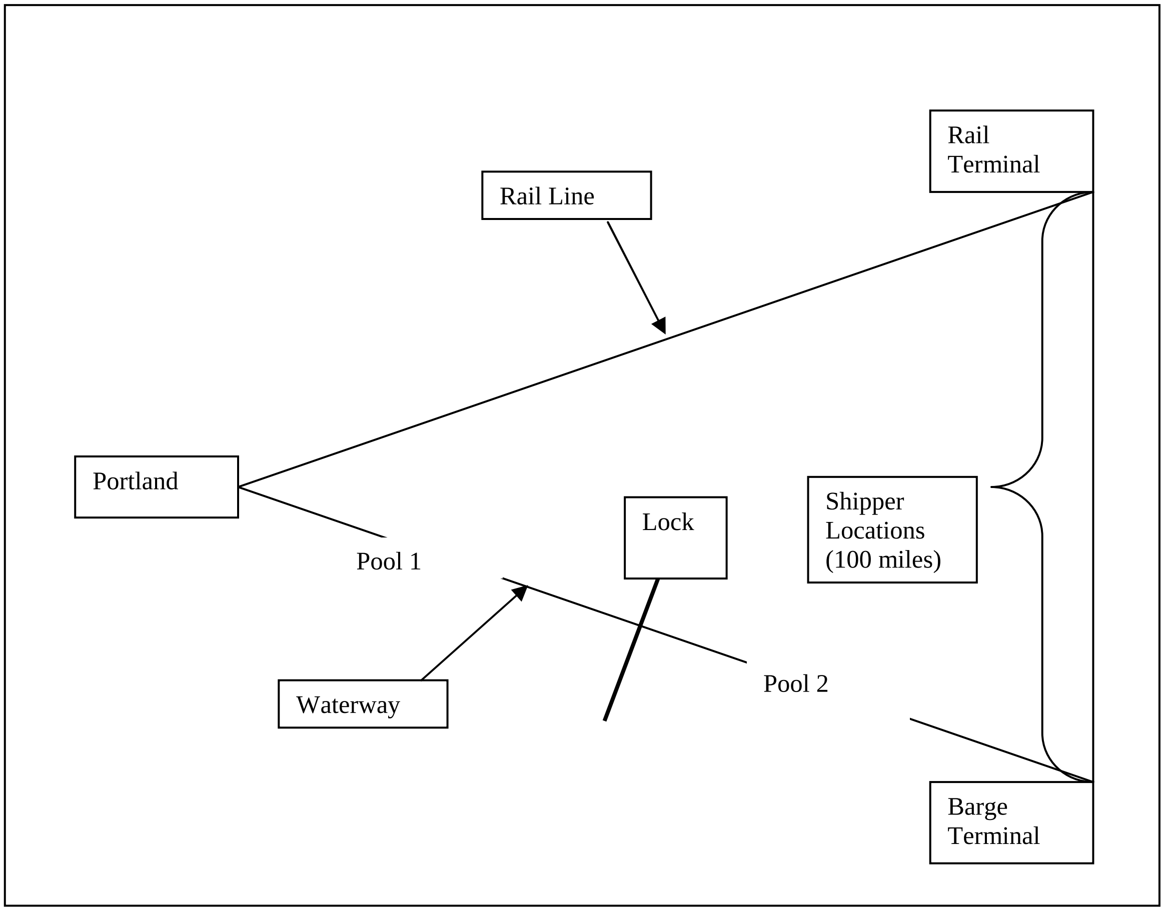


6.2 Pool Level Demand Schedules and Spatially Separated Demanders

Central to Army Corps of Engineer Planning models are “pool to pool” transportation demands by commodity. A pool is typically regarded as the body of water between two fixed points on the river. Most typically, the two points are two locks. In this illustration, there are two pools. One is the pool in which the terminal location of the total movement e.g., ocean terminals in Portland is located. The other pool is the pool above a lock where a barge access point i.e., a barge loading facility is located. The "pool" level demand is the aggregation of the individual shipper demands.[17]

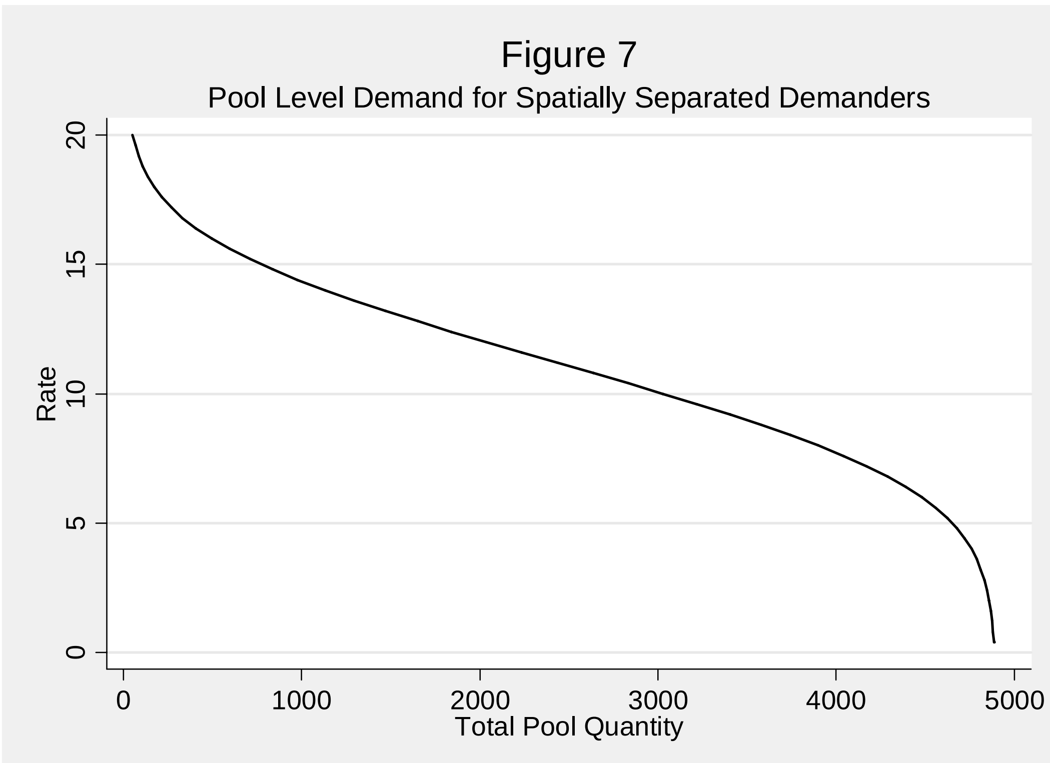
To illustrate, we construct a network. In that network (summarized in Figure 6), there are 50 shippers; each shipping 100 tons. The shippers are located two miles apart on a line connecting a barge access and a rail access facility. The access facilities are located 100 miles apart, and each are 350 miles from the terminal location.

Figure 6. Network for Illustration



[17] In this illustration, there is a single origin-destination-commodity (ODC) market for barge services. In this frame of reference, the ODC demand is the demand for lock services. In more complicated settings, there might be multiple ODC markets which share the services of an individual lock. In those cases, equilibrium may be obtained by using either the ODC levels or by using aggregations of the ODC markets to form a demand for lock services.

Given the network structure, all barge quantities can be aggregated to the barge terminal and, thus, provide the origin-destination-commodity triple that defines the demands that are commonly used in ACE modeling. The demand function is built on choice models, and the spatial environment of shippers. The demand function for the given structure and reference values is given in Figure 7.

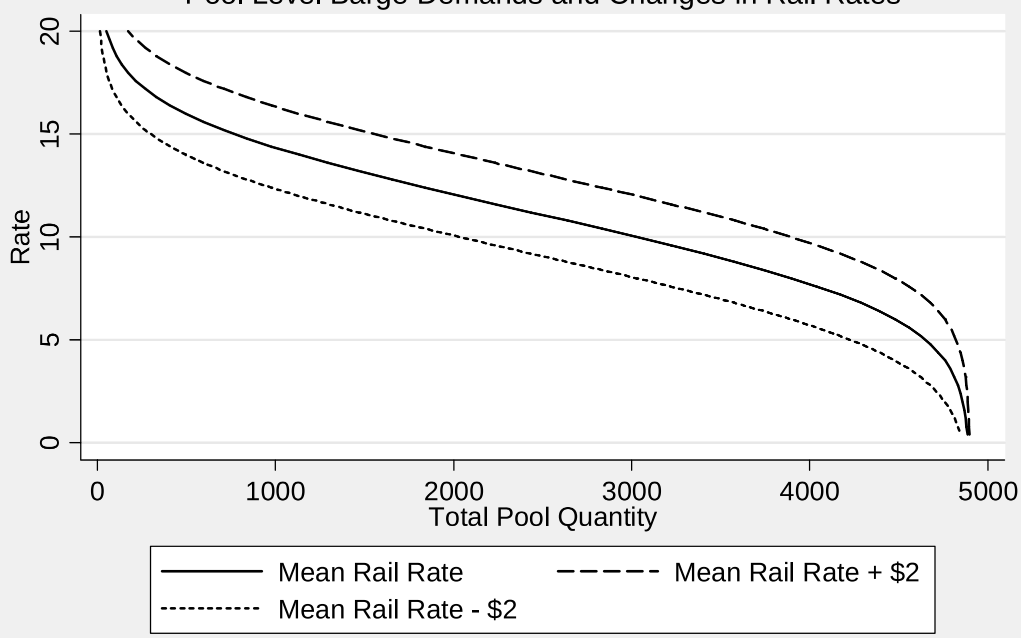


There are a total of 5000 tons that move from the region. At high barge rates, very little moves by water, while, at very low barge rates, most moves by water. At the predicted barge rate of about $9 per ton, about 3500 tons move by water (given a rail rate).

An important characteristic of such demand equations is the effect of substitution as rates change. Below, we consider the effects of changes in the rail rate. In this case, we generate, in addition to that of Figure 7, two additional demand schedules -- one with the rail rate reduced by $2 and one with the rail rate increased by $2. The result is presented in Figure 8. This figure indicates that when rail rates increase, the barge demand function shifts to the right, and when rail rates decrease it shifts to the left. The substitution effects appear quite large. Consider, for example, at a barge rate of 10 the quantity moved at the Mean rail rate is estimated as 3031. However, if the rail rate falls $2 from $11.3 to $9.3 per ton, the estimated quantity moved is about 2036; a 32 percent decline.

Figure 8

Pool Level Barge Demands and Changes in Rail Rates



7. EQUILIBRIUM AND CONCLUDING COMMENTS

Economic evaluations of markets are often made at fixed locations such as ports, pools, etc. However, the quantities shipped are from spatially distinct locations. The demands then are implicitly or explicitly generated from decisions made by spatially separated demanders. This research makes explicit the role of space in defining spatially aggregated demand functions which are central to establishing market clearing conditions to analyze the effects of policy. The spatially distributed demanders have options in moving goods to markets, and we illustrate in this paper that the choices made are directly connected to spatial considerations. The results illustrate not just choice modeling but also how the results can be used to inform ACE and other equilibrium models. In the specific case at hand, there is but one commodity-origin-destination triple. In this regard, equilibrium in the barge market obtains by adding the supply of barge transportation, equating the demand function above to supply and solving for the equilibrium *given rail rates*. Alternatively, rail supply (or pricing relations if railroads are not competitive) can be added to determine the rail and barge rates and quantities. In both cases, the total quantity moved is exogenous to the equilibrium. In this way, the equilibrium described here is equivalent to a modal split model (total quantity is moved is determined exogenously) such that only the modal split is endogenous.

There are a number of venues in which the apparatus above can be modified to allow for the total quantity moved to become endogenous, and the above framework can easily be adapted to accomplish this goal. In particular, the demand for transportation by mode as modeled above is the mirror image of the decision to supply the Port by mode. This supply decision can be complicated by a myriad of factors that essentially capture reservation prices of shippers (supplier of wheat to Portland) to the Port (storage, alternative terminal markets such as local markets for ethanol). In all of these cases, this means that the supply function has a non-zero slope. Another source beyond alternative points to supply (storage, local markets, alternative export markets), is the intensity of production. In the present case, all shippers ship 100 tons. If prices were higher, it is plausible that shippers (for at least some products) could be induced to produce more. In the present case, the total supply to Portland is perfectly inelastic and the total demand for transportation is fixed for the time period of analysis. This allows the barge equilibrium to be separated from its up or downstream markets. In grain markets, the resulting equilibrium rate levels may impact the intensity of production vis a vis the planting decision of the next or future time period(s).

If the supply of products to the Port has a non-zero slope, total supply, and therefore, transportation demand depends on the price at the Port. This model can be easily adapted to model equilibrium. Essentially, in our illustration, there is a demand for wheat in Portland that depends on a set of factors such as ocean rates to the importer both from Portland and other Ports considered, demand factors in the foreign country, etc. This demand is set equal to the supply of the commodity in Portland *which is identically equal to the sum of quantities shipped by each transportation mode to Portland*. This equality defines equilibrium in the Portland export market given equilibrium in the barge market. In this model, total quantities shipped, barge demands, and supply of wheat to Portland by barge, each depend on prices in alternative market, exchange rates, ocean freight rates, demands and supplies in foreign countries. This is the classic Samuelson-Takayama Judge type framework. Our contribution has been to aggregate the domestic supply of product by mode *in a full spatial framework*, and illustrate how transportation demand is a mirror image of supply by mode. Once estimated, the model can be adapted for a wide range of settings and shipper locations.

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